Department of
Environment and Conservation
Our environment, our future

Resource Condition Report for a Significant Western Australian Wetland

Leeman Lagoon

2008

Figure 1 – A view across the water body at Leeman Lagoon.

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Contents

1. Introduction

The current report considers the ecological character and condition of Leeman Lagoon, a permanently saline, gypsiferous lagoonal playa. The lagoon acts as an evaporative basin that receives drainage from the Pleistocene calcareous aeolianites of the Tamala Limestone karst system. Leeman Lagoon is situated within Holocene aeolian dune deposits as a salt-pan coastal lake. The lagoon lies across two shire borders within Beekeepers Nature Reserve in the Midwest region.

Leeman Lagoon was selected as a study site in the current project because it is a characteristic inter-dunal lagoon system and it is an important refuge for migratory birds. The lagoon was sampled by the IAI RCM project on 7 October 2008 and was previously sampled by the Salinity Action Plan survey on 29 September 1999.

1.1. Site Code

Register of the National Estate Place ID (Beekeepers-Lesueur-Coomallo Area and Nambung National Park): 105967.

Department of Environment & Conservation Nature Reserve: 24496.

Inland Aquatic Integrity Resource Condition Monitoring Project: RCM025.

Salinity Action Plan Wetland Biological Survey: SPS178.

Groundwater Dependant Ecosystem (Rutherford *et al.* 2005): GDE # 42.

1.2. Purpose of Resource Condition Report

This Resource Condition Report (RCR) was prepared by the Inland Aquatic Integrity Resource Condition Monitoring project (IAI RCM). The objective of the RCR is to set a benchmark against which future measures of condition can be assessed. This will allow the effectiveness of management planning and actions to be gauged. The report provides a summary of all available ecological information relevant to the site and describes the key drivers of, and threats to, the system. It provides a 'snapshot' of ecological character in 2008 and provides context for future monitoring of the site.

1.3. Relevant Legislation and Policy

This section provides a brief summary of the legislation and policy that is relevant to the management of Leeman Lagoon.

International

Migratory bird bilateral agreements and conventions

Australia is party to a number of bilateral agreements, initiatives and conventions for the conservation of migratory birds, which may be relevant to Leeman Lagoon. The bilateral agreements are:

JAMBA - The Agreement between the Government of Australia and the Government of Japan for the Protection of Migratory Birds in Danger of Extinction and their Environment, 1974;

CAMBA - The Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and their Environment 1986;

ROKAMBA - The Agreement between the Government of Australia and the Republic of Korea for the Protection of Migratory Birds and their Environment, 2006; and

The Bonn Convention on Migratory Species (CMS) - The Bonn Convention adopts a framework in which countries with jurisdiction over any part of the range of a particular species co-operate to prevent migratory species becoming endangered. For Australian purposes, many of the species are migratory birds.

National legislation

The Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)

The EPBC Act is the Australian Government's central piece of environmental legislation. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places - defined in the Act as matters of national environmental significance.

The seven matters of national environmental significance to which the EPBC Act applies are:

- world heritage sites;
- national heritage places;
- wetlands of international importance (‘Ramsar’ wetlands);
- nationally threatened species and ecological communities;
- migratory species listed under international treaties JAMBA, CAMBA and CMS;
- Commonwealth marine areas; and
- nuclear actions.

The EPBC Act regulates actions that will have, or are likely to have, a significant impact on any matter of national environmental significance. An action that will have, or is likely to have, a significant impact on a matter of national environmental significance is subject to environmental assessment and approval under the EPBC Act. An ‘action’ includes a project, a development, an undertaking or an activity or series of activities (http://www.environment.gov.au/epbc/index.html).

Australian Heritage Council Act 2003

Beekeepers Reserve, within which Leeman Lagoon is situated, has been placed on the Register for National Estate. The Australian Heritage Council Act protects places of National and Commonwealth significance.

Western Australia state policy

Wildlife Conservation Act 1950

This Act provides for the protection of wildlife. All fauna in Western Australia is protected under section 14 of the *Wildlife Conservation Act 1950*. The Act establishes licensing frameworks for the taking and possession of protected fauna, and establishes offences and penalties for interactions with fauna.

Conservation and Land Management Act 1987

This Act is administered by the State Department of Environment and Conservation (DEC) and applies to public lands. It sets the framework for the creation and management of marine and terrestrial parks, reserves and management areas in Western Australia, and deals with the protection of flora and fauna within reserve systems.

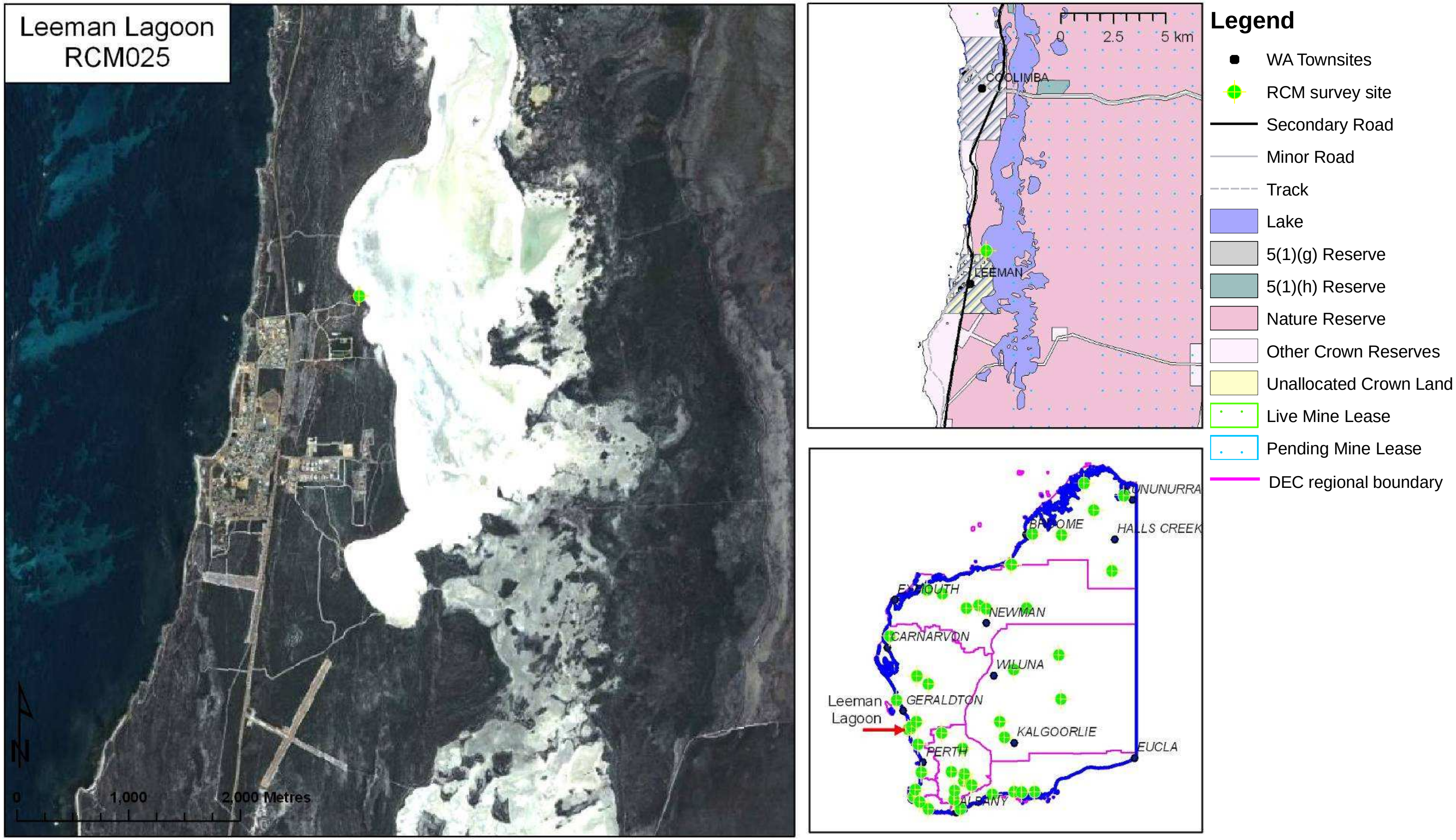

Figure 2 – Aerial photograph showing the survey location at Leeman Lagoon. The upper insert shows the position of the survey location relative to Leeman and Coolimba townsites. The lower insert shows the location of Leeman lagoon in the state of Western Australia and in relation to other RCM sampling sites.

2. Overview of Leeman Lagoon

2.1. Location and Cadastral Information

Leeman Lagoon (Figure 3) lies east of Leeman on the west coast of Australia. The survey location at Leeman Lagoon was approximately 650 m east of Indian Ocean Drive, immediately northeast of the Leeman townsite (Figure 2). The survey location was situated on the west side of the lagoon, with freshwater inlets present on the east side of the lagoon. The lagoon is a total of 21 km in elongated length, north to south, and is situated within the parabolic dunes of the Swan Coastal Plain.

The lake is contained within Beekeepers Nature Reserve (Class C), which was gazetted for the purpose of protection of flora. The Leeman townsite and the southern portion of Leeman Lagoon are contained within the Shire of Coorow. The northern portion of the lagoon extends into the Shire of Carnamah.

Figure 3 – Leeman Lagoon from the west bank.

2.2. IBRA Region

Leeman Lagoon lies within the Leseuer Sandplain (GS3) subregion of the Geraldton Sandplain Interim Bioregionalisation of Australia (IBRA) region. The Lesueur Sandplain subregion is comprised of coastal aeolian sands and limestone and Jurassic siltstones and sandstones (often heavily lateritised) of the central Perth Basin. There are extensive yellow sandplains in the southeastern parts, especially where the sub-region overlaps the western edge of the Yilgarn Craton. The vegetation primarily consists of shrub-heaths rich in endemics on a mosaic of lateritic mesas, sandplains, coastal sands and limestones (Desmond and Chant 2002).

Leeman Lagoon is actually more closely related to the SWA2 subregion of the Swan Coastal Plain IBRA region, which borders the lagoonal area to the south. The subregion is described as a low-lying coastal plain, covered mainly with open woodlands and coastal heathland in this northern area of the coastal belt. It is vegetated mainly with banksia on sandy soils and *Casuarina obesa* (She-Oak) on the outwash plains (Mitchell *et* al. 2002).

2.3. Climate

The nearest Bureau of Meteorology weather station to Leeman Lagoon is at Eneabba, 30 km away (BoM 2009). Records have been kept at Eneabba since 1964. Weather conditions at Leeman Lagoon are not expected to differ appreciably from those at Eneabba.

Eneabba experiences a dry Mediterranean climate, with wet winters and high (occasionally extreme) temperatures in summer. It receives a mean annual rainfall of 503 mm with most (69%) falling between May and August (Figure 4). Annual evaporation at Leeman is 2,200 mm (Kern 1997).

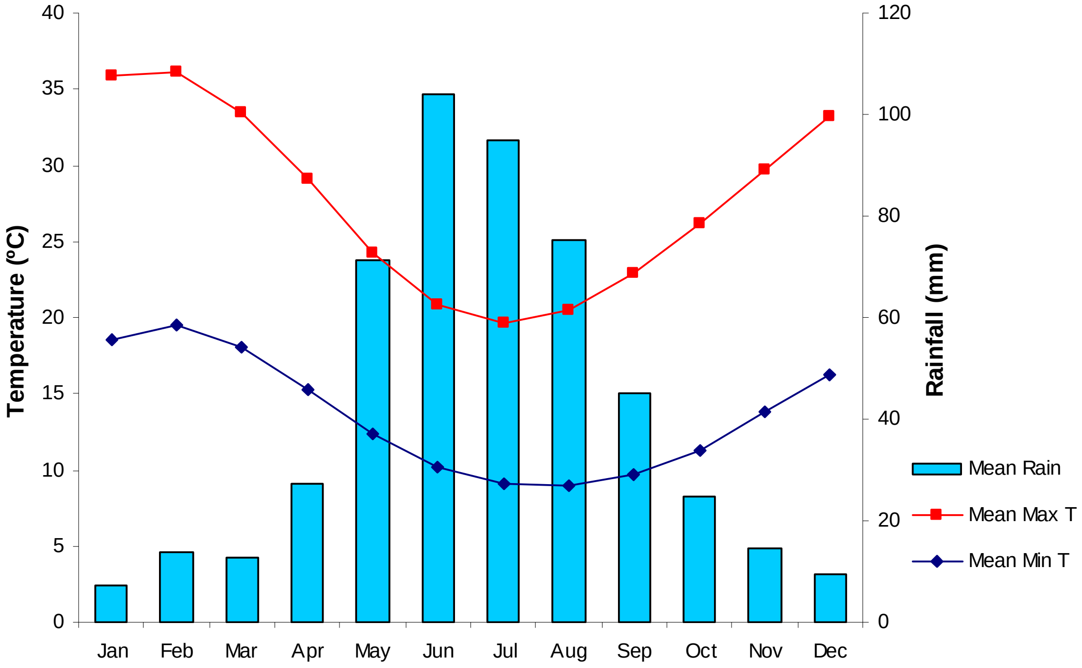

Figure 4 – Climatic averages for Eneabba, approximately 30 km northeast of Leeman Lagoon.

Leeman Lagoon was sampled on the 7th of October 2008. In the nine months preceding the IAI RCM survey (Jan – Sep 2008), Eneabba received 435.2 mm of rain. The most precipitation fell in July, with 153.1 mm of rain (BoM 2009). Houlder *et al*. (1999) estimates a higher annual precipitation of 577 mm at Leeman Lagoon, but this has not been influenced by a recent dry average.

2.4. Wetland Type

The Leeman Lagoon System is a near-permanent, shallow evaporative elongated lagoonal playa. The system has formed within an inter-dunal basin of Holocene sands upon the Quaternary sediments of the Tamala Limestone.

The Leeman Suite is described by Semeniuk (1994) as a suite of microscale to macroscale irregular shaped lakes, sumplands and damplands, located in the Coastal Limestone between Green Head and Coolimba. The wetlands are poikilohaline, ranging from hyposaline to mesosaline. Water is maintained in the wetlands through ponding and through groundwater conduits. Vegetation cover is predominantly open forest, shrubland and herblands, with cover usually peripheral or mosaic (V & C Semeniuk Research Group 1994).

When evaluated during the 1999 Salinity Action Plan survey, Leeman Lagoon was referred to as a 'Jurien Salt Lake' and was classified within wetland group 12 (WG12): a Naturally Saline Wetland – strongly seasonal, hypersaline shallow playa lake with sandy/clayey sediments, little organic matter and virtually no aquatic vegetation (Pinder *et al.* 2004).

2.5. Values of Leeman Lagoon

Values are the internal principles that guide the behaviour of an individual or group. Value systems determine the importance people place on the natural environment and how they view their place within it. Divergent values may result in people pursuing different objectives in relation to nature conservation, having different reasons for desiring a commonly agreed outcome, or favouring different mechanisms to achieve that outcome. Because of this, it is important to be explicit about the values that are driving conservation activities at a wetland.

The Conceptual Framework for Managing Natural Biodiversity in the Western Australian Wheatbelt (Wallace 2003) identified eight reasons that humans value natural biodiversity:

a. Consumptive use

Consumptive use is gaining benefit from products derived from the natural environment, without these products going through a market place. For example, the collection and personal use of firewood or 'bushtucker'. Wild Celery (*Apium annuum*) grows at Leeman Lagoon, potentially providing a source of bushtucker. The samphires *Sarcocornia quinqueflora* and *Halosarcia indica* are also edible plants found at the lagoon. Whether these plants are actually used for consumption is unknown.

b. Productive use

Productive use values are derived from market transactions involving products derived from the natural environment. The same firewood that is collected for personal use may be exchanged for money, or another commodity. Salt lakes to the south have been mined for gypsum. Other salt lakes of comparable quality have been used to farm algae such as at Hutt Lagoon, which has one of the largest production areas for β-carotene (Warren 2006). However, there are no known productive use values of Leeman Lagoon in the present day.

c. Opportunities for future use

Not all uses of the natural environment may be apparent at present. The potential for future benefit from the natural environment is maximised by maintaining the greatest possible biodiversity. Every lost taxa or ecosystem represents lost opportunities. Leeman Lagoon may support endemic or rare taxa. Such unique features would increase the potential for future opportunities to present. For example, the Priority 4 Conservation species *Grevillea olivacea* grows at Leeman Lagoon and may have potential in the future as a commercial cultivar.

d. Ecosystem services

There are many naturally occurring phenomena that bring enormous benefit to mankind. For instance, plants generate oxygen, insects pollinate food crops and wetlands mitigate floods by regulating water flows. The term 'ecosystem services', is used as a broad umbrella to cover the myriad of benefits delivered, directly or indirectly, to humankind by healthy ecosystems. Leeman Lagoon provides a refuge for the Hooded Plover (*Thinornis rubricollis*) and at least thirteen other waterbirds. The Priority 4 species Australian Bustard (*Ardeotis australis*) has also been recorded from this area (Foulds and McMillan 2003). Additionally, the presence of the extensive lagoonal barrier has reduced anthropogenic impacts on the eastern side of the lagoon due to reduced accessibility whilst protecting the Leeman townsite from wildfires that may occur to the east of the lagoon.

e. Amenity

Amenity describes features of the natural environment that make life more pleasant for people. For instance, pleasant views and shade or wind shelter from a stand of trees. It is difficult to quantify the amenity value of a site such as Leeman Lagoon, but it is certainly valued by the local community for the amenity it provides. A slight cooling effect would also benefit the township of Leeman during times when hot, eastern breezes prevail.

f. Scientific and educational uses

Parts of the natural environment that remain relatively unmodified by human activity represent great educational opportunities. Such sites allow us to learn about the changes that have occurred to the natural world. They are also ‘control’ sites that allow us to benchmark other, altered habitats. As the natural environment has been little studied here, there is significant potential for new scientific discoveries. The most comprehensive ecological study in the area to date had no aquatic component and was an east to west transect study undertaken in 1980/81, 11.5 km south of the IAI RCM survey location, by students from the Western Australian College of Advanced Education under Foulds & McMillan (2003). It is also possible that Leeman Lagoon may have a unique benthic microbial community. Diverse communities, due primarily to the presence of microbialites, have been found in lakes such as Lake Thetis near Cervantes. Such circumspection would require investigation.

g. Recreation

Many recreational activities rely on the natural environment (bird watching, canoeing, wildflower tourism, etc.) or are greatly enhanced by it (hiking, cycling, horse riding, photography, etc.). Recreation may deliver economic benefit derived from tourism and also delivers spiritual and physical health benefits to the recreator. Leeman Lagoon is used by the local community as a recreation site.

h. Spiritual/philosophical values

People’s spiritual and philosophical reasons for valuing the natural environment are numerous and diverse. One commonly cited is the ‘sense of place’ that people derive from elements of their environment. This is evident in many Aboriginal and rural Australians, who strongly identify themselves with their natural environment. Many people also believe that nature has inherent value or a right to exist that is independent of any benefit delivered to humans. A sense of spiritual well-being may be derived from the knowledge of healthy environments, even if the individual has no contact with them. Leeman Lagoon and the coastal area to the north are listed as an Aboriginal site of significance (DoW 2009).

The intent of nature conservation is usually to maintain the ecosystem service values, opportunity values and scientific and educational values at a given site. Doing so is likely to have positive effects on the amenity values, recreational values and spiritual/philosophical values to which the site’s natural environment contributes. Consumptive and productive uses of the natural environment are not usually considered, as these are often incompatible with nature conservation.

3. Critical Components and Processes of the Ecology of Leeman Lagoon

The primary objective of the Leeman Lagoon RCR is to identify, describe and quantify the critical components and drivers of the wetland’s natural environment. These components and processes determine the site’s ecological character and are the variables that should be addressed in any ongoing monitoring.

Climate and geomorphology are the most important drivers of wetland ecosystems. Between them, these factors determine the position of a wetland in the landscape and the type and hydrological regime of that wetland. In turn, a wetland's position, type and hydrology exert a strong influence on its biota and biochemical properties and processes.

A summary of Leeman Lagoon's critical ecosystem components is presented in Table 1, followed by a detailed description of the results of the IAI RCM 2008 survey as well as of any previous studies conducted on the wetland.

Table 1 – Summary of critical ecosystem components at Leeman Lagoon.

Component	Summary description
Geomorphology	Holocene coastal inter-dunal lagoonal playa over aeolianite calcrete.
Hydrology	Evaporitic basin fed by runoff and karst springs from Tamala Limestone
Water Quality	Basic (pH ~8.4); poikilohaline, brackish-saline; high phosphorous (1,400-1,500 μg/L)
Benthic Plants	Sparse small patchy macrophytes
Littoral Vegetation	Samphire & *Casuarina obesa* (She-Oak) woodland & *Melaleuca laceolata*
Invertebrates	27 species belonging to 17 families recorded
Fish	Some unidentified fish were seen in the lagoon
Waterbirds	Hooded Plovers in large numbers and >13 other species

3.1. Geology and Soils

Leeman Lagoon lies over the Pleistocene calcareous aeolianite of the Tamala Limestone. During Quaternary sea level fluctuations several episodes of marine transgression occurred, which allowed for the deposition of marine limestone in interdunal depressions. Underlying the laminar calcrete is breccia and/or massive calcrete. Downward gradation into the host sediment is through a mottled calcrete horizon. Arakel (1982) expanded his research into sedimentary processes of the evaporites to examine in depth the genesis of calcretes in both the Hutt and Leeman Lagoons.

Structure, textures, and fabrics were utilised to classify the following different calcrete types:

- *Pisolitic loose soil* is composed of sandy soils, calcrete ooids and pisolites, eolianite clasts, and shell fragments.
- *Laminar calcrete* is composed of parallel laminated sheets of micritic carbonate that develop by segregation processes.
- *Massive calcrete* is a dense, low permeability and relatively structureless calcrete with a "secondary" mudstone fabric, resulting from diagenetic alteration of primary constituents.
- *Calcrete mottles* form in response to localised diagenesis in the host sediment.
- *Breccia calcrete* develops as a result of prolonged weathering, involving repeated episodes of calcretisation, dissolution, and brecciation (Arakel 1982).

Diminution of permeability of the host sediment by the development of massive calcrete is a major process in genesis of the profile, and occurs in the lowermost part of the zone of alternate wetting and drying where the effect of water input overcomes the cumulative effects of evapotranspiration. Profile development is thereafter topographically controlled and restricted to horizons overlying the massive calcrete. The redevelopment of zones of alternate wetting and drying in older deposits has produced multiple soil profiles (Arakel 1982).

Lagoonal and estuarine deposits consisting of marl, shell beds, clay and silt would have been deposited by marine incursion and include the bivalves *Katelysia rhytiphora*, *Mytilus* spp., *Ostrea* spp., *Fragum* spp., small gastropods and foraminifers, minute spines from red algae, echinoids, crab shells and serpulid tubes. This faunal association is similar to that which occurs today with seagrass meadows in shallow restricted waters. The accumulation of sediments and restriction of marine circulation has correlated with a reduction in diversity of flora and fauna within Leeman Lagoon (Mory 1994).

Sampling by the IAI RCM project found the sediment of Leeman Lagoon was composed solely of fine sediments, which comprised 92% sand and 8% silt/clay.

3.2. Hydrology

Leeman Lagoon's function as an evaporative sedimentary deposit is coupled with calcium and iron-rich karstic inflows. This karst system includes laminar groundwater movement and focused flows such as the Stockyard Gully system. This system has a very diverse hydrology that has been influenced by extensive earthwork alterations to its catchment's drainage through a saline groundwater discharge trench made in 1984. This unnatural increase in unregulated flow caused a pulse-based flush of water to be increased in magnitude, carrying tons of saline sediment into the system. This should be considered in relation to current karst ecological dynamics that have altered in response to the lowered watertable and diminishing inflows (Susac 2008).

Lower Three Springs is in the area of direct groundwater recharge for Leeman Lagoon, which is itself connected to the east with the Three Springs 'oasis' of springs (this is not to be confused with the Organic Mound Springs of the Three Springs Area). At this location, water from the Eneabba Formation contributes to upward discharge before water percolates back into the Tamala Limestone. This formation also upwardly discharges along the Beagle Fault (Rutherford *et al.* 2005). Leeman Shallow bores (LS13a & 13b), approximately 6 km south-southeast of Stockyard Gully, have shown over a 2 m decline in levels since 2001 (DoW, 23 Jan 2008). This may be due to the influence of abstraction. LS-12 is located approximately 4.7 km south of the RCM survey location. The water abstraction bore-field of five production bores for the Leeman townsite is located in the vicinity of Lower Three Springs. These bores extract water from the Eneabba Formation below the superficial aquifer (Rutherford *et al.* 2005).

3.3. Water Quality

The results of water quality sampling of Leeman Lagoon by the IAI RCM survey and the Salinity Action Plan survey (Pinder *et al.* 2004) are presented in Table 2. Leeman Lagoon is slightly basic (pH approximately 8.4) and has variable salinity with the lagoon being fairly fresh (7.2 g/L) in 2008 but more saline (24 g/L) in 1999. The total phosphorous concentration was extremely high in both instances (1,400 and 1,500 µg/L).

Table 2 – Water quality parameters measured at Leeman Lagoon by the Salinity Action Plan and IAI RCM surveys.

	SPS178	**RCM025**
	29/09/1999	**7/10/2008**
pH	8.62	8.16
Alkalinity (mg/L)	100	135
TDS (g/L)	24	7.2
Turbidity (NTU)	2.6	3.7
Colour (TCU)	16	3
Total nitrogen (µg/L)	1,400	1,500
Total phosphorus (µg/L)	20	5
Total soluble nitrogen (µg/L)	1,400	1,200
Total soluble phosphorus (µg/L)	20	5
Chlorophyll (µg/L)	9.0	2
Sodium Na (mg/L)	6,580	25,800
Magnesium Mg (mg/L)	643	2,230
Calcium Ca (mg/L)	1,030	1,790
Potassium K (mg/L)	236	720
Chloride Cl (mg/L)	11,000	38,700
Sulphate SO_4 (mg/L)	3,200	6,770
Bicarbonate HCO_3 (mg/L)	122	165
Carbonate CO_3(mg/L)	<2	0.5
Silica SiO_2 (mg/L)	17	-

3.4. Benthic Plants

There was no aquatic vegetative cover in the lagoon near the vegetation transect.

3.5. Littoral Vegetation

A single 30-metre vegetation transect was established within 5 m of the water's edge on the western side of Leeman Lagoon (Table 3, Figure 5). The surrounding vegetation was dominated by *Casuarina obesa* (She-Oak) and *Melaleuca laceolata* low woodland.

Table 3 – Site attributes of the Leeman Lagoon vegetation transect.

Datum		WGS84
Zone		50
Easting		306037
Northing		6686785
Length		30 m
Bearing		140
Wetland state		Full
Soil state (%)	Dry	0
	Waterlogged	100
	Inundated	0
Substrate (%)	Bare	30
	Rock	0
	Cryptogam	0
	Litter	5
	Trash	5
	Logs	0
Time since last fire		no evidence
Community condition		Natural
Upper Stratum	Cover (%)	-
	Height (m)	-
Mid Stratum	Cover (%)	29.7
	Height (m)	<0.7
Ground Cover	Cover (%)	34.4286
	Height (m)	<0.3

This transect was established in a narrow strip at the base of the sand dunes within 5 m of the water's edge. The soil was waterlogged at the time of survey. Vegetation was dominated by *Tecticornia indica* subsp. *bidens*, *Sarcocornia blackiana*, *T. undulata* mid to high open samphire shrubland (29.7% cover, <0.7 m tall) over *Lolium rigidum*, *Crassula glomerata*, *Austrostipa flavescens* low open grasses and herbs (34.4% cover, <0.3 m tall). Figure 5 provides a complete list of taxa recorded along the transect RCM025-R1.

Shrubs were mature with no evidence of recruitment. Four weed species were recorded on the transect. Despite this, overall community condition was still considered 'natural' (Table 11 in Appendix 1).

Figure 5 – Leeman Lagoon vegetation transect RCM025-R1.

Table 4 – Plant taxa recorded along vegetation transect RCM025-R1 (in order of stratum then dominance).

Genus	Species	Height (m)	Stratum[1]	Form
Tecticornia	*indica* subsp. *bidens*	0.8	M1	Chenopod
Sarcocornia	*?blackiana*	0.4	M1	Chenopod
Tecticornia	*undulata*	0.5	M1	Chenopod
Tecticornia	*pergranulata* subsp. *pergranulata*	0.5	M1	Chenopod
Threlkeldia	*diffusa*	0.3	M1	Chenopod
Scaevola	*crassifolia*	0.7	M1	Shrub
**Lolium*	*rigidum*	0.2	G1	Grass
**Crassula*	*glomerata*	0.1	G1	Forb
Austrostipa	*flavescens*	0.3	G1	Grass
**Dischisma*	*arenarium*	0.1	G1	Forb
**Atriplex*	*prostrata*	0.2	G1	Chenopod
Samolus	*repens* var. *paucifolius*	0.3	G1	Forb

1 In an NVIS description, 'U' denotes the upper storey, 'M' the mid storey and 'G' the under storey (ground cover). Numerals to denote substrata from tallest to smallest (ESCAVI 2003).
* Introduced species
? Limited confidence in identification

According to the National Vegetation Information System (NVIS), the vegetation community may be described as (ESCAVI 2003):

M1+ ^*Tecticornia indica* subsp. *bidens*, ^*Sarcocornia ?blackiana*, *Tecticornia undulata*, *T.* sp. *Threlkeldia diffusa*\samphire shrub, chenopod shrub\2\i; G1 ^**Lolium rigidum*, **Crassula glomerata*, *Austrostipa flavescens*, **Dischisma arenarium*\tussock grass, forb\1\i.

Arakel (1980) recorded the Barrier Dune Sequence as being associated with an open scrub system dominated by *Acacia ligulata*. Other species have been recorded from the *Casuarina obesa* woodland wetland area 11.5 km to the south of the RCM025 survey location by students from the Western Australian College of Advanced Education under Foulds & McMillan (2003). These species are listed in (Table 5).

Table 5 – Plant species recorded and Leeman Lagoon by Foulds & McMillan (2003).

Family	Genus	Species
Euphorbiaceae:	*Phyllanthus*	*calycinus*
Fabaceae	*Gastrolobium*	*capitatum*
Lauraceae:	*Cassytha*	*glabella*
Mimosaceae	*Acacia*	*saligna*
Orchidaceae	*Caladenia*	*latifolia*
		menziesii
		longicauda

At 5.8 km to the north of the IAI RCM survey location, the Salinity Action Plan site recorded additional plant species in 1999 (Table 6).

Table 6 – Plant species recorded at Leeman Lagoon by the Salinity Action Plan survey.

Family	Genus	Species
Apiaceae	*Neosciadium*	*glochidiatum*
	Hydrocotyle	*medicaginoides*
Asteraceae	*Cotula*	*cotuloides*
	Pogonolepis	*stricta*
	Senecio	*pinnatifolius* var. *maritimus*
Centrolepidaceae	*Centrolepis*	*polygyna*
Convolvulaceae	*Wilsonia*	*backhousei*
		humilis
Cyperaceae	*Gahnia*	*trifida*
	Schoenus	*humilis*
Frankeniaceae	*Frankenia*	*pauciflora*
Chenopodiaceae	*Halosarcia*	*halocnemoides*
		indica
		syncarpa
	Sarcocornia	*quinqueflora*
Juncaginaceae	*Triglochin*	*mucronata*
Malvaceae	*Lawrencia*	*glomerata*
		squamata
		viridigrisea
Poaceae	*Parapholis*	*incurva* *
	Polypogon	*monspeliensis* *
		tenellus
Potamogetonaceae	*Ruppia*	*tuberosa*
Primulaceae	*Samolus*	*repens*
Zannichelliaceae	*Lepilaena*	*preissii*

* Introduced species

3.6. Aquatic Invertebrates

The Salinity Action Plan (DEC) undertook sampling of aquatic invertebrates (including microinvertebrates) at Leeman Lagoon on 29 September 1999 (Pinder *et al.* 2004). The survey recorded twenty-seven species of aquatic invertebrates, belonging to seventeen families (Table 7).

The IAI RCM survey recorded only two families of macroinvertebrates (microinvertebrates were not sampled): Oniscidae (Crustacea: Isopoda) and Chironomidae (Insecta: Diptera). The samples were not identified to species level due to time restrictions on the project.

Table 7 – Aquatic invertebrates recorded by the DEC Salinity Action Plan Biodiversity Survey in 1999.

Class	Order	Family	Lowest ID
Rotifera	Flosculariacea	Flosculariidae	*Ptygura* cf. *melicerta* (SAP)
	Ploimida	Brachionidae	*Brachionus plicatilis* s.l.
			Keratella shieli
			Notholca salina
		Lepadellidae	*Colurella adriatica*
		Lecanidae	*Lecane flexilis*
			Lecane sp. nov. d (Jurien)
Arachnida	Parasitiformes	-	Mesostigmata
Crustacea	Ostracoda	Cyprididae	*Australocypris insularis*
			Diacypris compacta
			Reticypris clava
			Platycypris baueri
	Copepoda	Cyclopidae	*Halicyclops* sp. 1 (nr *ambiguus*) (SAP)
			Apocyclops dengizicus
		Canthocamptidae	*Mesochra baylyi*
	Amphipoda	Ceinidae	*Austrochiltonia subtenuis*
	Isopoda	Oniscidae	*Haloniscus searlei*
Insecta	Coleoptera	Dytiscidae	*Necterosoma penicillatus*
	Diptera	Scatopsidae	Scatopsidae
		Tabanidae	Tabanidae
		Stratiomyidae	Stratiomyidae
		Chironomidae	*Procladius paludicola*
			Tanytarsus barbitarsis
			Polypedilum nubifer
	Lepidoptera	Pyralidae	*Pyralidae* nr. sp. 39/40 of JHH (SAP)
	Odonata	Lestidae	*Austrolestes annulosus*
		Hemicorduliidae	*Hemicordulia tau*

3.7. Fish

Unidentified fish were seen in Leeman Lagoon when sampled as part of the IAI RCM survey in 2008.

3.8. Waterbirds

A total of twenty-one birds associated with water have been officially recorded from Leeman Lagoon (Table 8). These records include the IAI RCM and Salinity Action Program Surveys undertaken by DEC, as well as two surveys conducted by the Western Australian College of Advanced Education (WACAE). The WACAE surveys, undertaken by students and led by Foulds and McMillan (2003), examined an area of Leeman Lagoon 11.5 km south of the IAI RCM survey location. The WACAE recorded a total of thirty-four species of birds, with thirteen of these directly associated with the aquatic environment. Fourteen other bird species were recorded from the *Casuarina obesa* woodland wetland area of Leeman Lagoon (Foulds and McMillan 2003).

In addition to these surveys, Birds WA recorded recent sightings of Hooded Plover (*Thinornis rubricollis*), a conservation status CS2 bird. Other reports of large numbers (42) of Hooded Plover have been recorded from this area (Mike Bamford; pers. obs.). This represents over 2% of the estimated species population for the South West (Bamford 2007). These beach-nesting birds are threatened with extinction because they struggle to breed successfully. The dune habitats they prefer are threatened by coastal developments, erosion and pedestrian traffic. Therefore, wetlands that support breeding habitat for Hooded Plover are of great conservation significance.

Of the species recorded, two are protected by at least one of the international migratory bird treaties: Great Egret (*Ardea alba*) and Caspian Tern (*Hydroprogne caspia*). Caspian Tern is a marine species, as is the Whiskered Tern (*Chlidonias hybridus*). These two marine species are found at Leeman Lagoon due to its coastal proximity, expansive geomorphology and saline water.

Table 8 – Waterbirds observed at Leeman Lagoon by the Department of Environment and Conservation (DEC) and the Western Australian College of Advanced Education (WACAE).

Organisation/Project Duration of project		**DEC/SPS 23/09/1999**	**WACAE 29/09/1999**	**WACAE 2003**	**DEC/RCM 07/10/2008**
Common name	**Latin name**				
Australian Wood Duck	*Chenonetta jubata*			✓	
Australian Shelduck	*Tadorna tadornoides*			✓	46
Black-winged Stilt	*Himantopus himantopus*			✓	
Black-tailed Native Hen	*Gallinula ventralis*			✓	
Black Swan	*Cygnus atratus*	2	✓	✓	
* Caspian Tern	*Hydroprogne caspia*	2			
Eurasian Coot	*Fulica atra*			✓	
* Great Egret	*Ardea alba*			✓	
Grey Teal	*Anas gracilis*	5			
Hardhead	*Aytha australis*	2			
Hoary-headed Grebe	*Poliocephalus poliocephalus*	4			
Little Falcon	*Falco longipennis*			✓	
Little Grassbird	*Megalurus gramineus*			✓	
Osprey	*Pandion haliaetus*			✓	
Pacific Black Duck	*Anas superciliosa*	1	✓	✓	
Peregrine Falcon	*Falco peregrinus*			✓	
Silver Gull	*Larus novaehollandiae*				2
Swamp Harrier	*Circus approximans*			✓	
Whiskered Tern	*Chlidonias hybridus*	13		✓	
White-faced Heron	*Egretta novaehollandiae*	1	✓	✓	
White-necked Heron	*Ardea pacifica*			✓	

* Listed under Migratory Bird Agreements JAMBA, CAMBA and/or ROKAMBA.
Numbers indicate abundance, if known.

3.9. Terrestrial Vertebrates

The most comprehensive ecological study in the area to date was an east to west transect study undertaken in 1980/81 in the *Casuarina* dominated wetland area of Leeman Lagoon, 11.5 km south of the RCM025 survey location. The survey was undertaken by students from the Western Australian College of Advanced Education under Foulds & McMillan (1983). They recorded two species of frog, Banjo Frog (*Limnodynastes dorsalis*) and Western Spotted Frog (*Heleioporus albopunctus*); and four species of reptile, Barking Gecko (*Underwoodisaurus milii*), Spine-tailed gecko (*Diplodactylus spinigerus*), Bobtail (*Tiliqua rugosa rugosa*) and Dugite (*Pseudonaja affinis*).

A rich diversity of species was recorded from the broader area of upland limestone heath-lands. The following introduced mammals, European Rabbit, House Mouse and feral Cat were also recorded.

4. Interactions between Ecological Components at Leeman Lagoon

An appreciation of the interactions between the elements of a wetland ecosystem is essential to understanding the condition of the system. Although components of a wetland are often monitored and managed as discrete entities, they exist as nodes in a complex ecological web. Documenting the full extent of the interactions that occur at a wetland would be impractical. However, it is essential to identify key interactions that define the system's ecological character.

Hale and Butcher (2007) justified the equivalence of Ramsar nomination criteria and primary determinants of ecological character. Accordingly, the primary determinants of ecological character at Leeman Lagoon are:

- The characteristics that make the site a good example of a wetland type occurring within a biogeographic region in Australia.

  Leeman Lagoon is a good example of an inter-dunal wetland type and a major evaporative basin occurring within the Geraldton Sandplain bioregion.

- The contribution the site makes to the ecological or hydrological functioning of the wetland system/complex.

  Leeman Lagoon is an evaporative salt playa that supports microbial algae. It is significant for the maintenance of ecological processes at a subregional scale (Desmond & Chant 2002).

- The animal taxa that utilise the site as habitat at a vulnerable stage in their life cycles, or as a refuge when adverse conditions such as drought prevail; and the characteristics of the site that allow it support these populations.

  Leeman Lagoon provides habitat for migrating waterbirds, such as Hooded Plover and Australasian bustard, that utilise the site as a refuge.

- The plant or animal taxa that have more than 1% of their national populations supported by the site.

  *The lagoon supports 2% of the Hooded Plover (*Thinornis rubricollis*) population in Western Australia.*

Table 9 summarises the interactions between key components and processes at Leeman Lagoon. The table lists the components that are directly responsible for the provision of each service or benefit of the wetland and the biotic and abiotic factors that support or impact these components. Also listed, are the key threats that may affect the components or processes. This information assists in the identification of the primary determinants of ecological character.

Table 9 – The relationship between the services and benefits delivered by Leeman Lagoon and the key components and processes that support them.

Benefit or Service	Component	Factors Influencing Component		Threats and Threatening Activities
		Biotic	Abiotic	
Opportunity Value Potential future use of unique flora and fauna	Endemic flora Endemic fauna	Pollinators Food sources	Habitat extent and distribution Hydrological regime Fire regime Water quality	Introduced animals Alteration to hydrology due to climate change, groundwater extraction or catchment perturbation Inappropriate fire regimes Weeds & introduced organisms; *Phytophora* spp.
Ecosystem Service Value It is a good example of an inter-dunal wetland type occurring within a biogeographic region in Australia	Leeman Lagoon is a good example of a major evaporative basin in the Geraldton Sandplain bioregion	Vegetation & fauna communities Algae	Hydrological regime Spring inflows Geomorphology Geology	Alteration to hydrology due to climate change, groundwater extraction or catchment perturbation Introduced animals Erosion Weeds & introduced organisms; *Phytophora* spp.
Ecosystem Service Value It is a wetland which plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex	Leeman Lagoon is an evaporative salt playa that supports microbial algae	Phytoplankton and algae Benthic plant biomass	Soil; calcrete/gypsum Hydrological regime Broad space Substrate precipitation	Alteration to hydrology due to climate change, groundwater extraction or catchment perturbation Erosion Weeds & introduced organisms; *Phytophora* spp.
Ecosystem Service Value It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail	Migrating waterbirds that utilise the site as a refuge	Invertebrate populations (food source) Phytoplankton (food source) Benthic plant biomass Littoral vegetation Vegetation communities	Fresh water springs Soils Nutrient concentrations Water salinity and pH Groundwater level Broad space	Alteration to hydrology due to climate change, groundwater extraction or catchment perturbation Inappropriate fire regimes Excessive nutrient inputs from stock Introduced animals Weeds & introduced organisms; *Phytophora* spp. Loss of migratory bird populations due to offsite factors

Benefit or Service	Component	Factors Influencing Component		Threats and Threatening Activities
		Biotic	**Abiotic**	
Ecosystem Service Value The wetland supports 1% or more of the national populations of any native plant or animal taxa	Supports 2% of the Hooded Plover *Thinornis rubricollis* WA population while on migratory paths	Invertebrate populations (food source) Phytoplankton (food source) Benthic plant biomass	Soils Nutrient concentrations Water salinity and pH Groundwater level	Introduced animals Alteration to hydrology due to climate change, groundwater extraction or catchment perturbation Inappropriate fire regimes Excessive nutrient inputs from stock Weeds & introduced organisms; *Phytophora* spp. Loss of migratory bird populations due to offsite factors
Recreational Value Bird watching Picnicking Bush walking	Landscape amenity Waterbird populations Vegetation communities Significant flora Significant fauna	Invertebrate populations (food source) Phytoplankton (food source) Benthic plant biomass	Soils Nutrient concentrations Water salinity and pH Groundwater level	Introduced animals Alteration to hydrology due to climate change, groundwater extraction or catchment perturbation Inappropriate fire regimes Excessive nutrient inputs from stock Weeds & introduced organisms; *Phytophora* spp. Loss of migratory bird populations due to offsite factors
Spiritual Value The wetland is of outstanding historical or cultural significance	Geomorphology of lake and surrounds Native flora and fauna communities	Flora and fauna populations Pollinators and food sources for above	Soils Hydrology Water quality	Introduced animals Alteration to hydrology due to climate change, groundwater extraction or catchment perturbation Inappropriate fire regimes Excessive nutrient inputs from stock Weeds & introduced organisms; *Phytophora* spp. Erosion

4.1. Primary Determinants of Ecological Character

4.1.1. Hydrology

Local groundwater recharge is from surface runoff and direct rainfall infiltration, and is supplemented by highly permeable Tamala Limestone springs from the east. The lagoon is an elongated basin playa that dries out into a salt pan, acting as an area of evaporative discharge from the karst (Rutherford *et al.* 2005). The Stockyard Gully Karst System is still intermittently active with large pulses of groundwater recharge occurring intermittently over broader timeframes. The last large pulse event was in 1999. Field investigations have revealed that during exceptional downpours rainwater percolates through the porous grainstones to recharge the local Tamala Limestone (Arakel 1982). Each year winter base-flow increases spring flow into the lagoon as subsurface water flows towards the ocean. The Stockyard Gully Karst System receives run-off from both: the Lesueur Aquifer and the Cattamarra Coal Measures (Commander 1981; Mory 1994). Groundwater movement within the Cattamarra Coal Measures and Lesueur aquifers is bounded by the Lesueur and Peron Faults to the east and the Beagle Fault to the west (Commander 1981). The water-levels of the lagoon are influenced by groundwater and tidal fluctuations as the lagoon has areas below sea level (Rutherford *et al.* 2005). The general direction of flow is to the northwest and the Kockatea Shale underlying the Tamala Limestone provides an impermeable base to prevent downward leakage. The closest spring to the RCM survey location is Lower Three Springs, 5 km to the southwest. Lower Three Springs and other inflow springs, along with Leeman Lagoon itself, have been identified by Rutherford *et al.* (2005) as a Groundwater Dependant Ecosystem.

4.1.2. Soil, Substrate and Geomorphology

Leeman Lagoon is situated within Quaternary aeolian deposits, in a wide shallow valley within the coastal Quindalup Dune System on the Coastal Plain of the Northern Perth Basin (Kern 1997). The sand to the west, forming this dune barrier sequence, is the Safety Bay Sand of the Quindalup Dune System and is 3.8 km in width; it overlies the Tamala Limestone and to the east the Spearwood Dune System. Soil profiles exposed along the margins of Leeman Lagoon contain a succession of calcrete horizons that exhibit oolitic-pisolitic grainstone, lithoclast breccia, and pelloidal wackestone-mudstone stone lithologies. The typical coastal profile consists of an upper laminar calcrete horizon which is usually overlain by a transitional pisolitic loose soil horizon (Arakel 1982).

Leeman Lagoon would have formerly been a marine embayment that is now cut off by Holocene, Quaternary dunes to become an increasingly segmented and elongated system. Arakel (1980) described in detail the genesis and diagenesis of the evaporitic sediments of the lagoon, beginning with the Basal Sheet Unit, 2.5 m thick in the central depressions of Leeman Lagoon. This unit is comprised of lithoskeletal grainstone and packstone of the abundant seagrasses *Posidonia australis* and *Amphibolus cymodocea* in the form of partly decomposed leaf sheaths and sparse spicules of sponges such as *Plectrninia halli*. Laminated layers of gypsite and mud laminae wholly composed of aragonitic mud pellets overlay this covering, an area of 28.5 km^2 and are up to 2.1 m in thickness. Then a 45 cm thick layer of gypsite dominates, which is continuous in the northern pond but discontinuous in the southern areas, where the RCM survey location is located. An Interclast Veneer Unit overlies this as a sheetlike body of pellet-grainstones covered in algal matt, that is overlain by the Ephemeral Halite Unit - prevalent in the northern pond at a 15 cm thickness covering 7.5 km^2. This halite is prone to dissolution during times of high seasonal inflow of water exposing the underlying algal matt. Various forms of evaporitic sediments have been identified with their environmental formation processes explained from the laminae, including prismatic gypsite, clastic gypsite, detrital gypsarenite and gypsrudite, nodular gypsite, hemipyramidal gypsum, anhydrite and bedded halite (Arakel 1980).

A comparative study of the Holocene-Recent marine, alluvial, and evaporitic sediments in the lagoon has been defined in summary with the following stages of evaporite basin evolution:

1) Open marine embayment stage; represented by a sheet of lithoskeletal Grainstone incorporating skeletal remains and seagrass leaf-sheaths.

2) Marine lagoonal stage; the accretion of coastal barrier beach and dune complexes progressively restricted open marine circulation resulting in changes in the faunal and floral assemblages and an upward fining of the marine sediment sequences.

3) Evaporitic pond stage; following the isolation of the lagoons from the sea, gypsum and mud layers developed as a result of alternating brine concentrations in the ponds. Rapid shoaling produced playas where lagoonal brines were confined below the sediment surface; locally subaerial exposure resulted in the reworking of earlier evaporites towards the lagoon centre. Subsequent winnowing of surface aeolian sediments facilitated the development of a veneer of pellet intraclast grainstone, which has since prograded basinward, forming extensive barren zones and salt-marsh flats.

4) Contemporary pond-playa stage; sedimentation is related to distribution and interaction of hydrologic units (groundwater, seawater, and lagoonal brines). Precipitation is restricted to ephemeral halite in ponded waters and the vadose diagenetic emplacement of $CaSO_4$ minerals in playa sediments (Arakel 1980).

5. Threats to the Ecology of Leeman Lagoon

The ambition for management at Leeman Lagoon is to maintain those elements of the ecology that make it an excellent example of an inter-dunal coastal evaporitic lagoonal playa in a relatively natural condition. The critical components of the ecology are the geomorphologic, hydrologic and water quality factors that make the lake a suitable stopover and refuge site for migratory birds. Such factors are the primary determinants of the lake's ecological character. They are influenced by, and exert an influence on, the vegetation communities that surround the water body, the aquatic invertebrate and benthic vegetation communities that inhabit it, and the threatening processes that face all of these. Also of importance, are the elements of the system that contribute to its cultural and scientific value. These are the same as the above listed influences on the primary determinants of ecological character, with the addition of landscape amenity. Although the condition of Leeman Lagoon is qualitatively considered good and its state as static (Desmond and Chant 2002), there are still potential threatening processes that should be considered.

Threats to Leeman Lagoon must be considered in relation to their likelihood of causing failure of the above management goal for the lake. An assessment is made of the probability that goal failure will result due to the impacts of each threatening process identified at the site, or potentially acting there. The results of this assessment are presented in Table 10. In summary, failure to achieve the management goal for Leeman Lagoon is most likely to result due to alteration to natural hydrological regimes. Pathogens and climate change are also significant threats, while the impacts of drought, flood, potential gypsum mining, weeds such as Poaceae; wild oats (Desmond and Chant 2002), and eutrophication of the water body should also be considered.

Recent dry years have reduced the superficial waters contained in the karst system to the east with several of the cave waters being completely absent from what has previously been described as 'permanent' pools. An unnatural increase in unregulated flow was caused by earthworks at the Stockyard Gully influx causing a pulse-based flush of water to be increased in magnitude carrying tons of saline sediment into the system (Susac 2008). Such a major alteration could have contributed to the colonisation of cave waters by *Cherax destructor* (Eastern Yabby) from eastern farmland (Jasinska *et al.* 1993). The presence of this introduced crayfish may have major implications to the ecology of the system. This includes, but is not limited to, displacement of native species, resource competition and the introduction of pathogens (Horwitz 1990). It is likely to subsist near freshwater outflows in the lagoon.

Table 10 – Threat assessment for Leeman Lagoon.

An estimate is provided of the perceived likelihood of goal failure resulting from the impacts of each identified threat category.

Goal: to maintain the geomorphology and hydrology of Leeman Lagoon, thus ensuring it remains a suitable drought refuge and migratory stopover for waterbirds and retains its cultural and scientific values.

Threat category	**Management issue**	**Probability that threat will cause goal failure with:**		**Assumptions underlying initial probability assessment and explanatory notes**
		Existing management	**Extra management**	
Altered biogeochemical processes	Hydrological processes, particularly watertable & inflow decline	15%	10%	Declines in water levels are evident in caves adjacent to Leeman Lagoon and in some of the Leeman Shallow monitoring bores (LS 13a and 13b).
	Carbon cycle and climate change	5%	5%	Increased times of drought which have occurred may compromise the integrity of the wetland but the wetland is conditioned to dry periods.
Impacts of introduced plants and animals	Environmental weeds	4%	3%	Due to the highly saline area of the lake, it is not expected to be highly susceptible to feral invasion.
	Herbivory and wallowing threats from introduced species	4%	2%	Not expected to be a significant threat due to the highly saline conditions. However, *Cherax destructor* could invade karstic spring areas. Pigs are known from the area and may wallow and seek water near spring inlets.
Impacts of problem native species	Overgrazing by native species	0.0	0.0	No impacts evident.
Impacts of disease	Plant pathogens	13%	8%	*Phytophthora cinnamomi* risk is higher with the 4x4 traffic. *Cherax destructor* has the potential to introduce disease (Horwitz 1990).
Detrimental regimes of physical disturbance events	Fire regimes	6%	3%	Prescribed burning fire regimes should be undertaken in Autumn as the most optimum time to reduce invertebrate mortality & allow for aestivation.
	Drought	5%	5%	Increased times of drought which have occurred will influence the community composition of the lagoon but the wetland is conditioned to dry periods.
	Flood	1%	1%	The Lagoon is adapted to sporadic events of heavy inundation.
Impacts of pollution	Herbicide, pesticide or fertiliser use and direct impacts	8%	2%	Catchment protection on the Eneabba Plain & Bassendean Sands will be important for the protection of Groundwater Dependant Ecosystems.
Impacts of competing	Recreation management	8%	3%	The main deleterious recreational impact is irresponsible off road traffic.

Threat category	Management issue	Probability that threat will cause goal failure with:		Assumptions underlying initial probability assessment and explanatory notes
		Existing management	Extra management	
land uses	Nutrient enrichment of water body	3%	1%	Leeman Lagoon is protected to the east by Beekeepers Nature Reserve so any enrichment would have to be very concentrated in the catchment area or in the immediate area of the lagoon. As the area east of the lagoon is the borefield for the towns of Leeman and Green Head, protection is assumed.
	Urban and industrial development	2%	1%	Although there is no major industry in the area, the town of Leeman is likely to expand bringing additional pressures. A very large increase in mining area in the Logue Catchment is proposed by Iluka and awaits approval.
	Consumptive uses	8%	5%	Water abstraction is the primary consumptive use of the underlying aquifer.
	Illegal activities	2%	1%	The dumping of waste, pollutants and feral organisms is the main concern.
	Mines and quarries	?	?	Although there is no quarry directly at the lagoon, applications for mining gypsum have occurred recently for salt playas to the south and north of Jurien.
Insufficient ecological resources to maintain viable populations	Habitat, genetic exchange	2%	1%	Leeman Lagoon is well-connected to the natural environment to the west. However, genetic exchange could be an issue regarding subterranean conduits with the decline in outflows into the lagoon affecting stygofauna. This includes water sourced from both the superficial and the Eneabba formations.

6. Knowledge Gaps and Recommendations for Future Monitoring

Hydrology

The most critical ecological factor of Leeman Lagoon is the groundwater dependant issues relating to the spring inflows and the aquifer system. The maintenance of the hydrology is highly important to both the local residents of Leeman and Green Head and the natural environment of the lagoon and its surrounds.

Water quality and fauna

It is recommended that the survey of waterbirds, conducted by the IAI RCM project, should be extended into monitoring, as these are an important value. It may be beneficial to also monitor the other side of the lagoon. As Leeman Lagoon is in a natural environment, it would be beneficial to establish a complimentary site the east side of the lagoon, closest to the most naturalised area and the fresh water spring inlets. This would ensure that sampling is representative of the entire system. It would be valuable to assess the community structure in the vicinity of these areas that may be in contrast to the generally more saline areas of the lagoon. An excellent example of an inflow in the central eastern portion of the lagoon has been identified at 2.05 km east-northeast of the RCM survey location. This area appears as to be the most obvious and largest inflow area for the entire Leeman Lagoon Complex. This spring is exactly 7.8 km west of E-10, mentioned in section 4.7 as a site sampled for aquatic invertebrates.

As the last comprehensive ecological study including terrestrial fauna was undertaken in 1981, it is apparent that this should be repeated again, specifically in the central Leeman Lagoon area. This study was an east to west transect study and would be valuable on both sides of the lagoon. However, it is predicted that the west side will provide a higher biodiversity due again to the influences of freshwater springs and connectivity with a broad area of native vegetation, namely limestone heathland, which was recorded as having the highest levels of biodiversity in the previously mentioned study (Foulds and McMillan 2003).

Invasive species, agriculture, mining and fire

If the springs were to be monitored in the future, it should be determined whether they have been colonised by yabbies. Colonisation by this invasive species is apparent in the cave waters and has been evident at Leseueur National Park and poses a threat to native Koonacs (*Cherax plebijus*) found there (CALM 1995). These areas should also be monitored for the impacts and visitation of other introduced animals. There are currently no quantitative data on the effects of introduced predators, weed colonisation, fragmentation, farming impacts, fires or the impacts of mineral extraction on gypsum and lime surfaces (Desmond and Chant 2002).

Vegetation and groundwater

It is also likely that the vegetation assemblage present in the vicinity of these freshwater springs and seeps will be considerably different to the vegetation complex described in this report, which was more representative of the western shoreline. The other spring site of significance is in the area of Lower Three Springs, 5 km to the southeast of the RCM survey location. This Groundwater Dependant Ecosystem area is set back from the lagoonal shore at the interface of the Tamala Limestone with the Holocene sediments. The reason for monitoring this area is from a public groundwater protection perspective, as the borefield is situated in this vicinity. Similarly, it would be valuable to use water tracing techniques to observe water movement through the landscape in areas such as the upper Three Springs on the other side of the Tamala Limestone karst and at E-10. This would only be possible after a significant pulse based rain event (>50 mm rainfall in the catchment in one day). Such events are very uncommon and therefore it would be worth having approvals and plans in place in contingency for such an event. This would provide information for water catchment mapping, planning and management in the event of up-stream contamination.

Borehole monitoring of the Leeman Shallow borehole series and the Eneabba line will be conducted by the Department of Water. This monitoring will provide an understanding of the catchment condition and provide windows for sampling. However, most bores are screened to observe deeper aquifers. There are no boreholes in the vicinity of the Tamala Limestone area of Stockyard Gully. It would be valuable if a series of piezometer/observation wells could be installed into the Stockyard Gully stream-bed to observe the superficial aquifer levels at this important inflow area. Installation in the streambed would avoid the bulk of the Tamala Limestone, which is difficult to penetrate, and allow sampling from a broader area of surface catchment, providing an indication of general catchment condition.

Groundwater dependent ecosystems

There are currently $2.46 million (+ GST) available for a National project to assess the vulnerability of Groundwater Dependent Ecosystems (GDE) in the Midwest. The project will define the ecological, social and cultural values of groundwater-dependent ecosystems and will use representative GDE sites to obtain information on their susceptibility to groundwater regime change based on distribution, deposition and age of sedimentary rocks and vegetation water requirements found at those sites. A groundwater-monitoring network and vegetation transects will be established, allowing managers to understand water requirements, including information on ecological condition. A risk analysis of GDEs will then be carried out, based on scenarios of groundwater regime change due to climate variability and/or development pressures.

This project, scheduled to end in July 2011, will compliment the suite of work already undertaken in Western Australia in the other high-priority areas. Together, these studies will result in improved groundwater-management guidelines for these vulnerable areas.

In addition to providing essential understanding about groundwater-dependent ecosystems in the Midwest and the hydrology that supports them, this project will significantly contribute to the revision of water management plans in line with National Water Initiative and state water reform requirements. It will assist in the assessment of water required for the environment and water available for use, and will define areas at risk of abstraction. Such information can be used to inform licensing decisions.

The information gathered will support the development of environmental water provisions and a statutory groundwater management plan for the Northern Perth Basin. The monitoring program established will be used to evaluate the effectiveness of water management and water use strategies in meeting environmental and management objectives, enabling an adaptive approach to management of the water resource. This is fundamental to achieving the sustainable outcome of maximising water development while minimising environmental impact (National Water Commission 2009).

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Appendix 1 – Vegetation Condition

Table 11 – Overall Vegetation Community Condition Rating as adapted from Thackway and Lesslie (2005). Shading indicates the condition of Leeman Lagoon.

Overall Community Condition Rating					
	0	**1**	**2**	**3**	**4**
	RESIDUAL BARE	**NATURAL**	**IMPACTED**	**DEGRADED**	**REMOVED/REPLACED**
Community Condition Class	Areas where native vegetation does not naturally persist	Native vegetation community structure, composition and regenerative capacity intact - no significant perturbation from land management practices	Native vegetation community structure, composition and regenerative capacity intact but perturbed by land management practices	Native vegetation community structure, composition and regenerative capacity significantly altered by land management practices	Species present are alien to the locality and either spontaneous in occurrence or cultivated. Alternatively, vegetation may have been removed entirely
Regenerative Capacity	Natural regenerative capacity unmodified - ephemerals and lower plants	Regenerative capacity intact. All species expected to show regeneration are doing so	Natural regenerative capacity somewhat reduced, but endures under current/past land management practices	Natural regenerative capacity limited and at risk due to land management practices. Rehabilitation and restoration possible through removal of threats	Regenerative potential of native vegetation has been suppressed by ongoing disturbances. There is little potential for restoration
Vegetation Structure	Nil or minimal	Structural integrity of native vegetation is very high. All expected strata, growth forms and age classes are present	Structure is altered but persists, i.e. some elements of a stratum are missing	Structure of native vegetation is significantly altered, i.e. one or more strata are missing entirely	All structural elements of native vegetation are missing or highly degraded
Vegetation Composition	Nil or minimal	Compositional integrity of native vegetation is very high. All species expected at the site are present	Composition of native vegetation is altered. All major species are present, although proportions may have changed. Some minor species may be missing	Significant species are missing from the site and may have been replaced by opportunistic species. Loss of species affects structure of vegetation	Native vegetation removed entirely +/- replaced with introduced species

Appendix 2 – Herbarium Plant Records

Table 12 – Herbarium Records for Leeman Lagoon.

Search Coordinates: NW corner 29.9281°S, 114.9881° E; SE corner 29.9802°S, 115.0284°E

Family	Species	Alien	Cons. Status
Proteaceae	*Grevillea olivacea*		P4
Malvaceae	*Alyogyne huegelii*		
Myrtaceae	*Darwinia neildiana*		
Myrtaceae	*Eucalyptus rigidula*		